ENVELOPE GENERATORS & SEQUENCERS FOR ELECTRONIC MUSIC

Shaping tones or notes and determining combinations or order.

BY DON LANCASTER

ANY electronic music system needs some means for specifying the shape and sequence of the tones or notes produced. The equipment to accomplish this can range from an extremely simple keyboard-controlled on/off manual to elaborate sequential attack/sustain/decay generators and on up to complete digital computer synthesis sequencing that specifies everything about the notes and their time order.

Any device that shapes the individual notes is called an envelope generator or ASD (attack/sustain/decay) controller. If some circuitry is determining what tones or notes are to

follow in a given combination or order, we call it a sequencer. Sequencers can operate on fixed rhythm and chording patterns, on random patterns from a composer circuit (as "teach-and-learn" devices), or as part of an elaborate computer system that bases what it will do on a set of compositional guidelines.

We have already seen in previous articles on electronic music that, if we obtain a waveform that represents the amplitude-versus-time of a desired note, all we must do is route it through a keyer or vca to let it modulate either a basic frequency reference or a complex tonal structure. Either way, we

eventually end up with a tone whose frequency and amplitude components are specified throughout its duration. So, where does the initial envelope waveform come from and how do we generate it?

Envelope Generation. In Fig. 1 are illustrated some of the things we might want to build into a single note or tone. For the sake of simplicity, assume that the frequency structure of the tone will remain constant for the tone's duration. (If it does not, simply use more of the same techniques, routing some of the envelope commands to filters instead of to keyers or vca's.) This leaves us with the basic amplitude shape shown. Now, let us examine the individual parts of our note.

ATTACK is the initial rise time of the note. It usually ranges from a few to several hundred milliseconds. Attack waveforms often have a rising exponential, while linear and capacitor charging waveforms are more often used in electronic music since they are much simpler to generate. With the exception of horn blips, the exact changes in the total attack time do not usually have a profound effect on the final tone structure.

HORN BLIP is a characteristic single or double implusive "blip" that often appears in a horn voicing, giving it the characteristic "bite" of the trumpet and other brass instruments. It is often obtained electronically by summing a brief impulse wave shape with the normal envelope waveform.

PEAK VALUE is the maximum amplitude, often reached at the end of the

Oberheim Electronics DS-2 Digital Sequencer
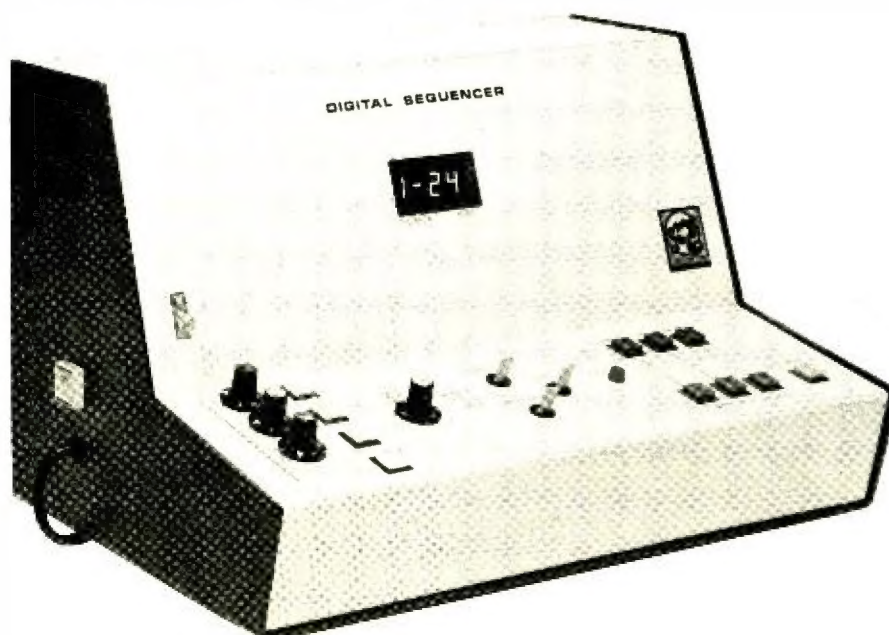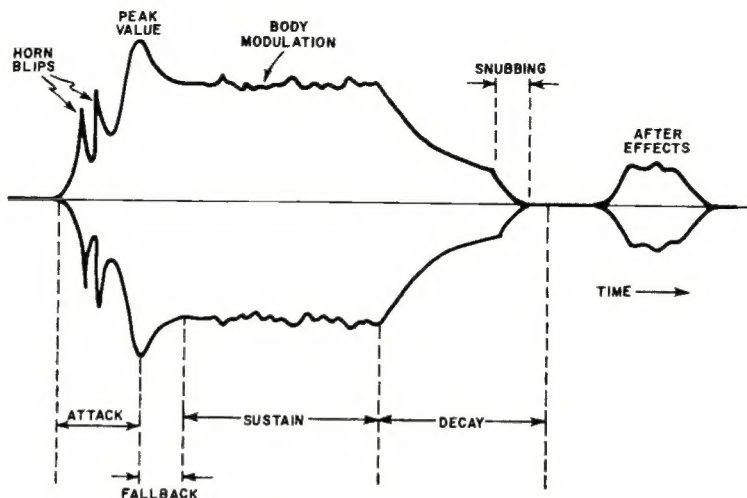
Fig. 1. Envelope of a note showing various characteristcs.

attack period. Some traditional instrument imitations—particularly the English horn—have a two-value attack in which much of the initial amplitude is rapidly reached. This is followed by a much slower rising response to the peak value.

FALLBACK is the portion of the waveform from peak level down to zero or some intermediate level. Many voices—particularly percussion—drop rapidly from a peak to some intermediate level as initial transients and other high-frequency effects rapidly die down. A classic example of this is a bell that gives an initial loud "clang." followed by a long drawn out pure bell tone. Fallback is essential for most percussion voices, particularly in piano synthesis.
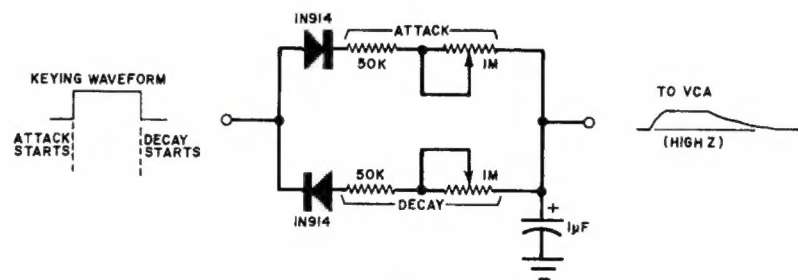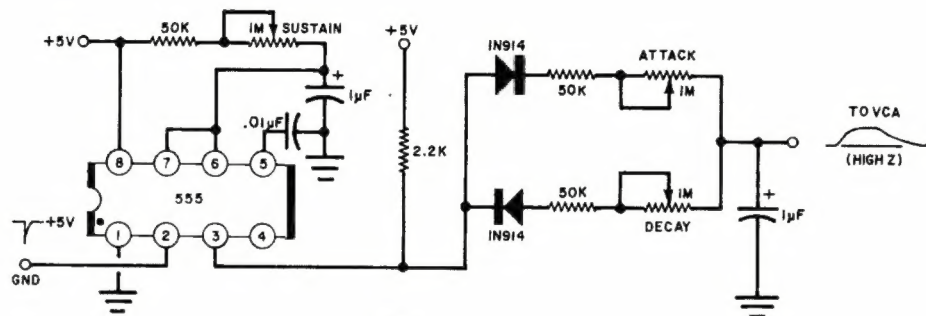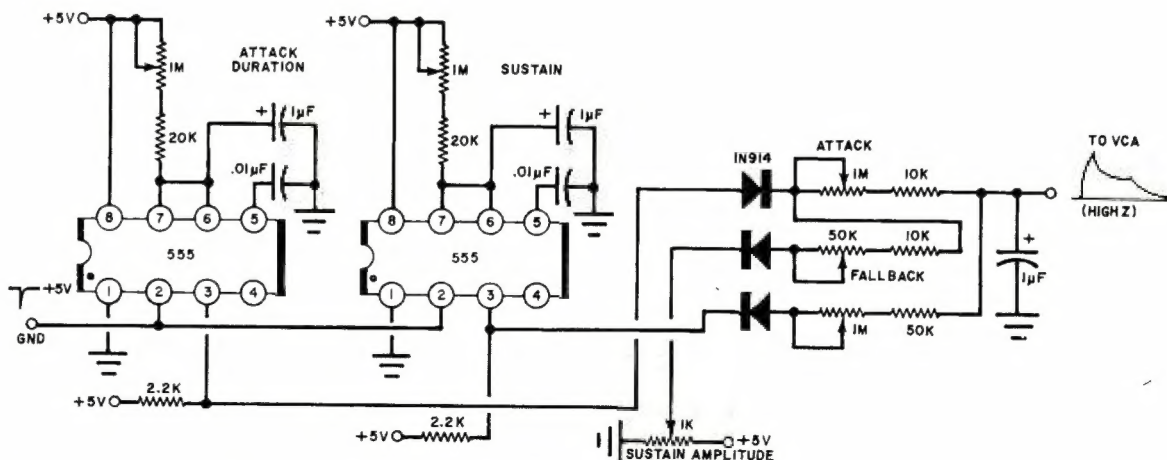
Fig. 2. At (A) is simple attack/sustain/fallback/decay circuit controlled by musician.
Circuits (B) and (C) perform same function but are controlled by monostable oscillators.

SUSTAIN is the dwell period during which a note remains at relatively constant amplitude. It can be very short in duration or missing altogether in a percussion note. In fact, a percussion can be redefined as a note with a short or missing sustain time that is not under the immediate control of the musician. If the musician can hold the note for a controlled time, we have a non-percussion voice.

BODY MODULATION is any additional amplitude effect that is added to the note during the sustain period. A deep 6- or 7-Hz tremolo characteristic of piccolo or flute voice is one possibility. Another is the addition of random noise variations to break up an "exactitude" (electronic sound). In traditional instruments, this might take the form of wind noise, bowing noises, etc. At the other extreme, we could use all random noise for the body of the note, as is the case with some percussion effects. As the noise is filtered more and more, the greater the degree of filtering, the more it will appear as a pure tone. Hence, with either filtering or randomizing techniques, we can obtain anything from a purely random hiss to a pure "code practice oscillator" tone. The most musical of the effects are obviously between these limits.

DECAY is the drop-off at the end of the note. In reality, the decay is almost always exponential in form, although higher-frequency components often drop off at exponential rates that are different from those for the lower-frequency components. Decay times range from a fraction of a second to several seconds and are usually much longer than the attack times. (This can be reversed in electronic circuits to yield a "tape played backwards" type of effect.)

Since the decay is the last thing to occur in a note, and since it is relatively long in duration, obtaining the best waveform possible here is very important. A true exponential decay (or—better yet—several of them working on different harmonic components) must be used. A linear decay approximation will sound unreal. A truncated decay will sound even worse. And a decay that does not quite go to zero will produce note feedthrough and background noise. Fortunately, the normal RC discharge of a capacitor is a simple exponential decay, although you must be sure the level to which you are discharging represents the zero-amplitude point of

your keyer or vca without truncation or feedthrough.

SNUBBING is a truncation technique that is used when you want to purposely terminate the decay cycle early. This snubbing most often crops up when you are synthesizing the release of a piano key. A snubbing waveform is usually nothing but a sudden speeding up of the decay time constant, causing a very rapid (but usually a non-zero) decay.

AFTER EFFECTS can be reverberation, echo, or any of a number of special effects. They are normally generated separately with the aid of a reverberation or tape-delay technique.

If we examine all of the characteristics wanted in a note, we can see that we need an attack/fallback/sustain/decay waveform as our basic envelope generation technique. Onto this, we can add such things as horn blips, noise modulation, snubbing, and echo effects to increase the range of total variations at our command.

while circuit (B) performs the same functions but this time is controlled by a single monostable oscillator (555). By overlapping the attack and decay times, we can get a percussion voice with zero sustain.

Circuit (C) has added to it a second monostable oscillator to provide complete control of attack/fallback/sustain/decay shaping. All three circuits are based on charging a capacitor with one resistor that sets the attack time and a second resistor to discharge the capacitor and set the decay time. In circuit (C), a second resistor also discharges the capacitor at the end of the attack period but shuts off automatically whenever the remaining capacitor voltage drops below the sustain amplitude value. You can also vary circuit (C) to permit sequential operation of the monostable oscillators with the first controlling attack, a second fallback, a third sustain, a fourth decay, a fifth snubbing, and so on.
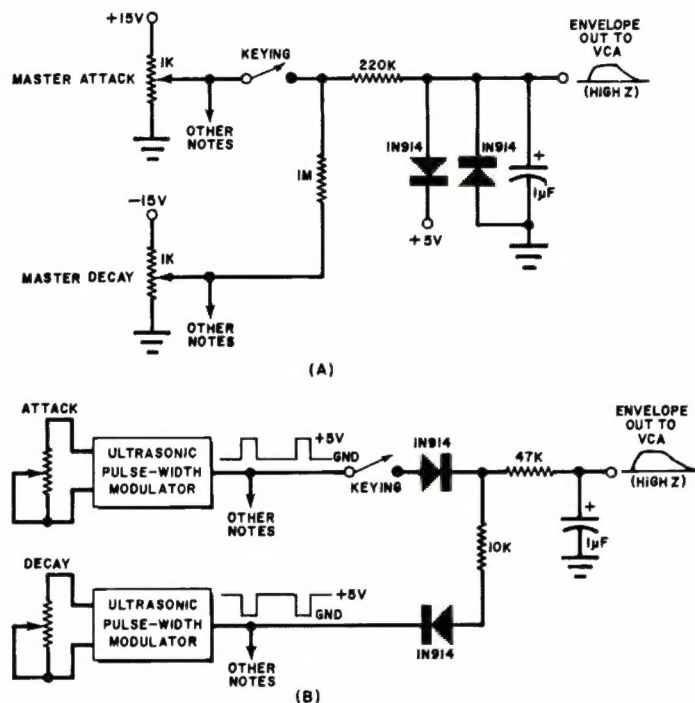
Fig. 3. Circuit (A) has two master controls for attack and decay; (B) uses ultrasonic pulse-width modulation.

Now, let us turn to some simple circuits that will do the job.

Envelope Circuits. Three simple attack/sustain/fallback/decay circuits are shown in Fig. 2. Circuit (A) is a simple attack/sustain/decay that is under the control of the musician,

All three circuits shown in Fig. 2 can be only lightly loaded, which means that they can be connected to a keyer or vca that has a high input impedance, on the order of more than 3 megohms. A simple voltage follower, FET follower, or emitter follower circuit can be added as required for a
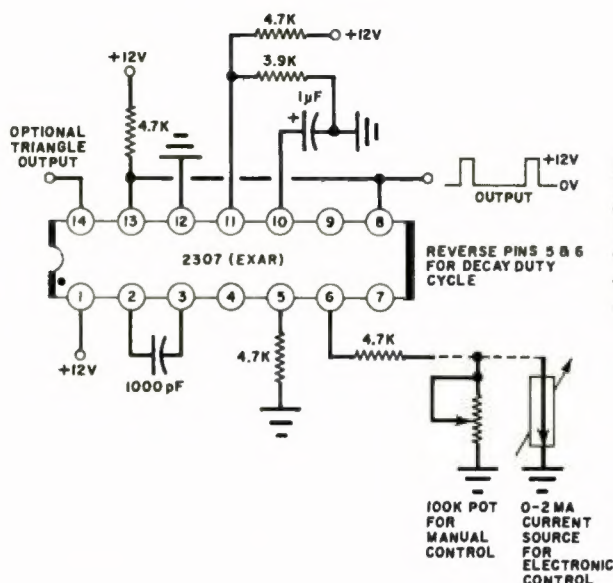
Fig. 4. *Typical pulse-width modulator. Two are needed for complete control of all keys.*

rent through it for one-tenth the steady-state current time, and the resistor would appear to have a value of 470,000 ohms, which most conveniently gives us the ability to remotely control dozens or even hundreds of resistors (and the resulting attack and decay times) simultaneously.

To accomplish the above, we have two pulse sources whose duty cycles are controlled by potentiometers or control voltages. These operate at ultrasonic frequencies, charging and discharging the envelope capacitor in very small steps. The slope of each step is set by the charging or discharging resistor, while the total height of each step is set by the ratio of the on to the off times of the modulator. Since each step is a tiny fraction of a decibel in height, and since there are many thousands of them during the evelope generation period, the net result is the same as if the capacitor were charged and discharged.

A typical pulse-width modulator is shown in Fig. 4. While the IC costs about $4 (from EXAR Inc., 750 Palomar Ave., Sunnyvale, CA 94086), only two are needed for complete control of all keys, with low-cost diodes doing the actual switching. In this setup, the attack waveform is routed through the keyboard's contacts. If this is objectionable, a CMOS logic gate or analog switch can be substi-
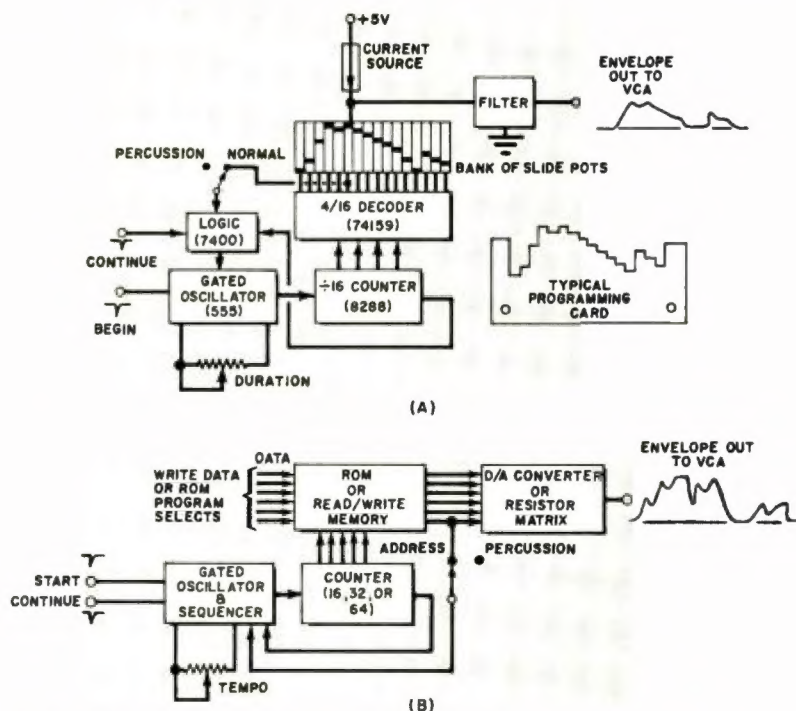
lower impedance keyer or gain control circuits.

Each of these circuits must have its attack and decay times set separately. The problem now is how to obtain polyphonic operation so that only one or a very few controls set the overall attack for all notes simultaneously, while a second group of controls is assigned to the decay function. Two possible approaches are illustrated in Fig. 3, one of which is a brand new and very powerful technique.

In circuit (A) is a MASTER ATTACK for all the notes and a MASTER DECAY control that serves all notes in a polyphonic instrument. Keying charges the output capacitor in the positive direction, increasing the volume of the vca until a potential slightly greater than 5 volts is reached. At this point, the positive clamping diode goes into conduction and limits the capacitor voltage to a maximum amplitude value. Releasing the key discharges the capacitor, eventually clamping at ground potential at the note's end.

For long attack and decay times, the charge rate is exponential (actually one minus the exponential on the charge cycle and the exponential on the discharge cycle). However, as either the attack or decay times are shortened, the charging rates become more linear. This would be objectional but for the fact that the linear rates are associated with the shorter times and are thus difficult to notice. Nevertheless, this is an extremely simple and useful polyphonic circuit.

The better technique is shown in circuit (B). This technique is called ultrasonic pulse-width modulation

(UPWM). It is fully polyphonic, can be controlled by digital logic or some other easy means, and provides true exponential decay characteristics that are instantly variable, even from a remote location, over a wide range.

The trick to this circuit's operation is to rapidly switch resistors inside and outside the charging circuit. A 47,000-ohm resistor appears as a 47,000-ohm resistance when current is flowing through it. Reduce the current to zero, and the resistor behaves like an infinite resistance. Pass cur-

(A)

(B)

Fig. 5. *Output of binary counter is shaped by programmed pots in (A). In (B), pots are replaced by digital memory.*

tuted as the control element, since the signal is really a digital waveform up to the diodes. This technique can easily be extended to include fallback, percussion, and other effects.

Purely digital techniques can also be used for generating the envelope, but as of now, their added complexity limits them to monophonic instruments or, at best, to a time-shared or priority hierarchy in an instrument. Two typical digital circuits are shown in Fig. 5.

In circuit (A), we use an input time reference from a start/stop oscillator to count out 16 counts of a binary counter. Each count is decoded and routed to a slide-type potentiometer. Using slide pots, you can "draw" the waveform you want and set the total duration with the frequency of the time references. You can let the circuit go completely around for a nonpercussion voice. Releasing the key then continues the cycle. So, when you press a key, you generate the first five levels of the envelope. It then sticks in, say, position 5 for as long as the key is held down. On releasing the key, the note will continue through the decay cycle. As with most envelope schemes, some type of memory, usually a sample-hold or a digital latch, is essential if the key's frequency is to be remembered after the key is released.

The main advantage of the slide-pot scheme is its extreme versatility, especially since you can generate all manner of envelope shapes that are unreal or extremely difficult to generate with a traditional instrument. These include echo, multiple bursts, reverse attack, etc. One limitation of this scheme is that you really should use more than 32 slide pots, and another is that the tolerance of the pots can be rather restrictive as you are setting each slider to a slightly different value from its neighbor.

Programming the circuit is quickly accomplished with a plastic program card, first homing the sliders and then using the card to set them to the desired values. Once your favorite envelopes are chosen, you can install fixed resistor matrices that can be switched into the circuit in place of the pots in either preset or stop fashion.

Circuit (B) replaces the analog slide pots with a purely digital memory. For initial setups and experiments, you can use a read/write or random-access memory (RAM). For performance and concert use, a read-only memory (ROM) can be used to rapidly

Fig. 6. Sequencer techniques: (A) has rhythm generator; (B) generates random patterns; (C) is teach/learn device.

select any of a number of fixed envelopes.

Sequencers. Three popular sequencer techniques are shown in Fig. 6. A sequencer governs the order and combinations the notes follow, rather than the shape of each individual note. Technique (A) has a rhythm generator or sideman. An early version of these circuits appeared in POPULAR ELECTRONICS as the "Drummer Boy" (July 1971). Today, you can do the whole thing with a single S8890 IC from American Microsystems, Inc. (3800 Homestead Rd., Santa Clara, CA 95051) or the M250 IC from SGS-ATES (435 Newtonville Ave., Newtonville, MA 02160). The IC's are available at about $25 in unit quantities. Both IC's generate the combination rhythm patterns for rhythm accompaniment and are available in a standard pattern (traditional rhythms) as well as in custom patterns at much higher cost. Electrically, the IC's operate in much the same manner as circuit (B) in Fig. 5.

Circuit (B) in Fig. 6 is a composer/synthesizer that employs a pseudo-random sequencer to generate ran-
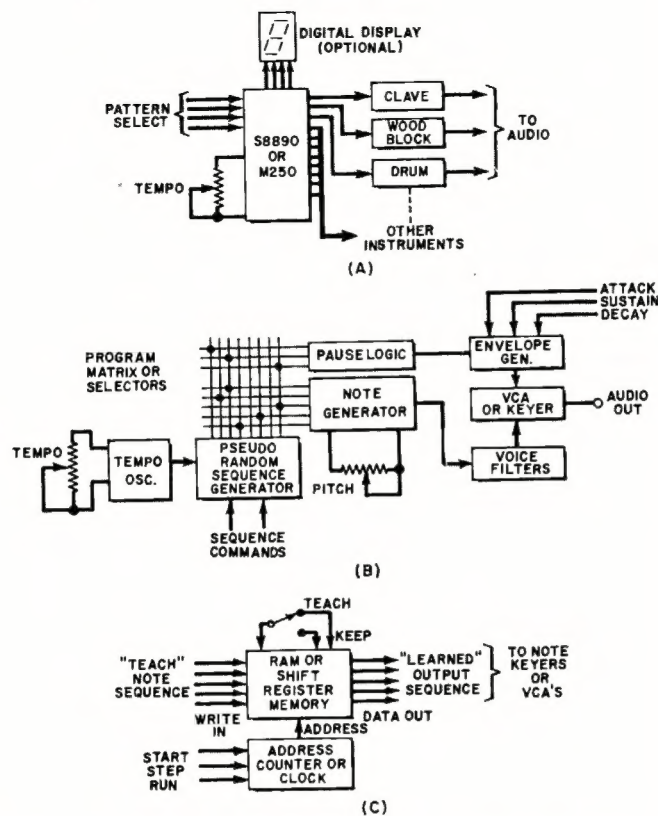
dom tone patterns. These patterns are combined with program selectors and pause selectors to generate hundreds of thousands of tonal sequences, and at around $50 cost much less than most synthesizers. One such random-pattern generator was the "Psychtone I" that appeared in this magazine as a construction article in February 1971 and is still available in kit form from Southwest Technical Products Corp., 219 West Rhapsody, San Antonio, TX 78216.

Circuit (C) in Fig. 6, a variation of circuit (B) in Fig. 5, is a teach/learn sequencer. A commercial version called the Model DS-2 is available from Oberheim Electronics (1549 Ninth St., Santa Monica, CA 90401). Teach/learn devices of this type can employ either RAM's or shift-register memories. One good choice for experimenters would be the Signetics hex 32- and hex 40-bit shift registers (2518 and 2519), particularly since they are beginning to appear on the so-called "surplus" market for as little as 25¢ each. Brand new IC's directly from the factory are currently selling for less than $5 and form the basis for many teach/learn music experiments. ◈